TNO Color Survey with the VLT: Pilot Observations with the Science Verification Camera*

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Abstract. In the framework of the Science Verification of the first 8.2m telescope of ESO's Very Large Telescope, several TNOs were observed in order to measure their magnitude and colors. We present and dicuss these results.

1 Introduction and Observations

The Science Verification (SV) Program of ESO's Very Large Telescope (VLT) Unit Telescope 1 took place between August 17 and 31, 1998. Several observation programs were performed, covering a broad range of astronomical topics, in order to verify the suitability of the telescope for astronomical observations. The data, including those on which this paper is based, were released on October 1, 1998 (ESO 1998).

One of the SV programs was aimed at obtaining magnitudes and colors of a set of TNOs. Indeed, a significant fraction of our knowledge of the TNOs' physical properties is based on these parameters (Davies 1998). The typical magnitude range of the TNOs ($R \sim 20$–25) put these objects at the faint limit of the objects for which accurate photometry can be obtained on a 2–4m-class telescope; indeed, fairly long exposures (typically 15–20min), under good sky conditions, are required to acheive a signal-to-noise ratio suitable for color studies (i.e. a few percents). Moreover, with such telescopes, only a few objects are observable each night. With an 8.2m like the VLT Unit Telescopes, the exposure times can be reduced and/or the S/N increased, allowing many objects to be observed during one night. A complete survey of all the minor bodies in the outer Solar System could be performed in just a few nights, resulting in an uniform survey.

* Based on observations collected at the European Southern Observatory, Paranal, Chile (VLT-UT1 Science Verivication Program)

The SV programs were performed by the Paranal astronomers (Science Verification Team). They selected the observations that were most suited for the weather and seeing conditions. The TNO program was designed as a "back-up", to take advantage of the periods of poor seeing (although the median seeing of Paranal is $\sim 65''$, it is not uncommon to have a seeing of up to $\sim 2''$ during some winter nights). Although no time was originally assigned to this program, a total of 3.4h was finally spent on the TNOs, with a seeing varying between 0.7 and $2''$.

The observations were performed using the Science Verification Camera on the VLT UT1. This camera is a imager involving three internal reflections, designed to produce a clean pupil. The detector is a 2k$\times$2k Tektronics CCD (TK2048EB-1522BR07-01) of thechnical grade. It suffers from a large ($\sim$ 300pix) blemish close to the center of the chip, whose sensitivity is very different of the rest of the CCD, and which proved to be hard to correct for using traditional flat-field. The observers took care not to place the objects in that region. The detector was read in a 2$\times$2 bin read-out, resulting in a pixel size of $0.09''$.

The objects were pre-selected for the quality of their orbit. The actual selection was performed by the observers, based upon the observability of the targets at the time of the observations. Table1 lists the objects various related parameters. The observations were obtained through the standard Bessel filters, in a sequence R B R V R I R. The repetition of the R filter allows us to monitor the transparency of the sky during the observations, and to disentangle the effects of the rotation (change of the cross-section) from genuine color effects.

The photometric calibration was obtained by measuring various photometric fields. The whole data reduction was handled by the Science Verification Team: they performed the standard bias subtraction and flatfield correction, and computed the photometric transformation for each night and each filter. The images relative to two objects were not released by the VLT (because of their bad image quality). The TNOs were then identified by blinking the different frames. 1996 KV1, whose motion was very slow at the time of the observations, could not be identified, even after comparing the frames with images of the same field obtained several days later. It is suspected that the object was in front of one of the many stars crowding the field.

The object instrumental magnitudes were measured using the MAGNITUDE/CIRCLE command of the MIDAS package, using a diaphragm of $4''$ diameter. The sky was measured in a ring centered on the object, whose radii were 10 and $15''$. The sky value is obtained by taking a σ-clipped mean of the level in that region. The instrumental magnitudes were corrected of the instrumental and atmospheric effects using the calibration relation provided by the SV Team. No correction was performed to take into account the light that would escape the $4''$ diaphragm.

Table 1. Observation Log

Object	Date [UT]	R[AU]	Δ[AU]	Mag.	Seeing	Exp.Time	Notes
1993 RO	1998-08-24	31.4	30.6	23.1	0.6-1.0	600s	
1994 TB	1998-08-26				1.-2.7	60-100s	1
1996 KV1	1998-08-29	40.8	40.5	23.8	0.9-1.5	300s	2
1996 TL66	1998-08-24	35.1	34.7	20.6	0.6-1.0	60-100s	
1996 TO66	1996-08-26				¿2	60-100s	1
1996 TP66	1998-08-24	26.4	25.8	20.9	0.6-0.7	60-100s	

Date refers to the UT epoch of the observations; R and Δ are the helio- and geocentric distances to the object. Mag refers to the expected magnitude of the object (using the information from the MPC web server). Seeing is a measurement of the FWHM images (in arcsec). Exp.Time lists the exposure times that were selected by the Science Verification Team. Notes: 1. Observations not released; 2. Object not found.

2 Results

Table 2 lists the magnitudes and colors obtained. The R magnitudes were converted into absolute magnitudes, and into radii using an albedo of 0.04.

Table 2. Magnidutes, colors and radii

Object	B	V	R	I	$B-V$	$V-R$	$R-I$	Rad
1993 RO		24.37	23.63	23.15		0.74	0.48	52
		±0.03	±0.03	±0.03				±2
1996 TL66	21.81	21.46	20.83	20.46	0.35	0.63	0.37	237
	±0.04	±0.04	±0.04	±0.04				±9
1996 TP66	22.89	21.86	21.27	20.62	1.03	0.58	0.66	108
	±0.04	±0.04	±0.04	±0.04				±4
Calib. error	±0.02	±0.02	±0.01	±0.02				
Ext. error			±0.06					

The ± listed in the table correspond to the photon noise from the object and the sky in the diaphragm. Calib. error refer to the error listed on the photometric calibration provided by the SV team, and Ext. error is the RMS of the 4 R measurements of each object. Rad is the radius [km] of the object derived from the R magnitude, assuming an albedo of 0.04.

It should be noted that the colors obtained (esp. for 1996 TL66) present some discrepencies with respect to the values published by others (cf, for instance, Davies 1998). Part of these discrepencies are explained by the fairly large error caused by the very short integration time (60sec) used for these images. While it is also possible that the measurement method introduced some systematic effects in the magnidude obtained (cf general workshop discussions held at the Bar of Am Park Hotel), these would probably affect all filters in a fairly similar way, and therefore should not affect the colors in a very large way.

The magnitudes obtained from the 4 R images on each objects are constant within the error bars, indicating no rotational effect, and confirming the photometric stability of the sky during the observations.

The R images for each object were registered on the position of the TNO and co-added. A photometric profile was then extracted and compared to that built from various field stars. The TNO profiles don't show any excess compared to the stars, indicating no resolved coma. It should nevertheless be noted that the surface brightnesses reached (25.5 for 1996 TL66 and 1996 TP66, 28 for 1993 RO) were not very constraining because of the relatively short exposure times involved. For instance, Delahodde et al. (1998) reached more constraining surface brighnesses for 1996 TO66 on a 3.6m, integrating longer.

3 Conclusion and Projects

This short program proved the suitability of the VLT for TNO studies: colors were measures on 3 objects, using short exposure times, with poor seeing conditions. It should nevertheless be noted that the S/N obtained in 60sec exposures was not optimal: if a full scale survey is launched, longer exposures will be selected. Assuming 300s as a typical typical exposure time, accurate 4-band colors would be measured in 1/2h per object. Four VLT nights would be sufficient to perform a complete, uniform survey of all the TNOs known to date. Observations with FORS (VLT spectro-imager in the visible range) could be combined with additional data from ISAAC (spectro-imager in the near-infrared), to cover a broader spectral range. We can therefor expect to have a complete TNO taxonomy by the next MBOSS meeting.

References

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